MULTI-AXIS SOLID STATE ACCELEROMETER

FIELD OF THE INVENTION

[0001]   The present invention relates to an electrical capacity solid state accelerometer made by micro-machining techniques and more particularly, to an accelerometer for detection of acceleration in two or more axes.

BACKGROUND OF THE INVENTION

[0002]   A conventional three-axis solid state accelerometer is shown in Figure 1 of the attached drawings, comprising a proof mass 32, a plurality of sensing beams 42 connecting the proof mass 32 to a proof mass 31 surrounding the proof mass 32. The proof mass 32 is only moveable along y-axis. Electrodes 52p and 52n are located on opposite sides of the proof mass 32 and parallel to x-axis so as to form two y-axis sensing capacitors c92p and c92n.   A plurality of sensing beams 41 connects the proof mass 31 to a proof mass 33 surrounding the proof mass 31 so that the proof mass 31 is only moveable along the x-axis.   Electrodes 51p and 51n are located on two sides of the proof mass 31 and parallel to the y-axis so as to form two x-axis sensing capacitors c91p and c91n.   Two sensing beams 43 connect the proof mass 33 to anchors 60 fixed to boards 71 and 72 so that the proof mass 33 is only moveable along z-axis.   Electrodes 93p and 93n are located on the boards 71 and 72 and correspond to the two surfaces of the proof mass 33.   The electrodes 93p and 93n form two z-axis sensing capacitors c93p and c93n on two sides of the proof mass 33.

[0003]   When acceleration occurs in the y-axis, the y-axis sensing capacitors c92p and c92n detect the acceleration due to the change of their capacitances resulting from change of spaces.

[0004]   When acceleration occurs in the x-axis, the x-axis sensing capacitors c91p and c91n detect the acceleration due to the change of their capacitances resulting from change of spaces.

[0005]   When acceleration occurs in the z-axis, the z-axis sensing capacitors c_{93p} and c_{93n} detect the acceleration due to the change of their capacitances resulting from change of spaces.

[0006]   Two deep and narrow spacing parallel surfaces have to be formed when making the x-axis and y-axis capacitors of a conventional accelerometer. The process for making the two deep and narrow spacing surfaces employs surface micro-machining or dry etching, and the aspect ratio is reduced when the depth is increased.   This limits the sensitivity of the accelerometer.

[0007]   The present invention propose to change the structure of the sensing capacitors, when a component of acceleration parallel to the main surface moves the proof masses, the area of the capacitors is changed rather than changing the gap of the capacitors so that the two deep and narrow surfaces are needed.   The requirement of the aspect ratio can be omitted so that the process is simplified.

SUMMARY OF THE INVENTION

[0008]   In accordance with an aspect of the present invention, there is provided an capacitive type multi-axis solid-state accelerometer which involves easy manufacturing process, no high aspect ratio required, increasing the yield-rate and reducing the manufacturing cost.

[0009]   Furthermore, the conventional accelerometer does not disclose the characteristics of the present invention.

[0010]   The present invention will become more obvious from the following description when taken in connection with the accompanying drawings, which show, for purposes of illustration only, preferred embodiments in accordance with the present invention.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0011]   Figure 1 shows a conventional accelerometer wherein the drawing (a) is a top view of the main structure and the drawing (b) shows a cross sectional view of the main structure;

[0012]   Figure 2 is a first embodiment of the three-axis accelerometer of the present invention, the drawing (a) shows the top view of the main structure, drawing (b) shows the stripe electrodes of the detection capacitor on the glass board, drawing (c) shows the cross-sectional view of the accelerometer;

[0013]   Figure 3 is a second embodiment of the three-axis accelerometer of the present invention, the drawing (a) shows the top view of the main structure, drawing (b) shows the stripe electrodes of the detection capacitor on the glass board, drawing (c) shows the cross-sectional view of the accelerometer;

[0014]   Figures 4 and 5 show two different types of a third embodiment of the three-axis accelerometer of the present invention;

[0015]   Figures 6 and 7 show different types of the second and the third embodiment of the three-axis accelerometer of the present invention;

[0016]   Figure 8 shows the second embodiment of the three-axis accelerometer of the present invention that is made by micro-machining on a (110) silicon chip.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0017]   Figure 2 shows a first embodiment of the three-axis accelerometer in accordance with the present invention wherein Figure 2a shows a top view of the main structure and includes three proof masses 31, 32, 33 made of electricity conductive material.   The three proof masses 31, 32, 33 are connected to a frame 2 or fixing anchors 60 by sensing beams 41, 42, 43.   The frame 2 or the anchors 60 are fixed to boards 71, 72.   The sensing beams 41, 42, 43 make the proof masses 31, 32, 33 movable only along a first axis, a second axis parallel the boards and z-axis which

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is perpendicular to the boards. The proof masses 31, 32 each have grooves 31t and 32t that are perpendicular to the first axis and the second axis.

[0018] As shown in Figure 2b, two sets of interposed stripe electrodes 91a and 91b parallel to the grooves 31t are located corresponding to the grooves 31t on the board 71, 72 and electrically connected to bond pads 91p and 91n, respectively, so as to form a first axis detection capacitors c91p and c91n with the surfaces of the block 31. Figure 2c shows positional relationship between the electrodes 91a, 91b and the groove 31t on the first axis. When the acceleration along the first axis, the proof mass 31 causes a displacement on the first axis, the capacitances of the first axis sensing capacitors c91p and c91n change because of the change of the effective area. The changes of the two capacitances are opposite to each other so that the first axis acceleration can be detected by checking the difference of the capacitances of the two capacitors c91p and c91n. The detected signal can be fed back by a feedback circuit, which is not shown, to the first axis capacitors c91p and c91n, and the proof mass 31 remains still.

[0019] Two sets of interposed stripe electrodes 92a and 92b parallel to the grooves 32t are located corresponding to the groove 32t on the boards 71, 72 and are electrically connected to bond pads 92p and 92n, respectively, so as to form a second axis detection capacitors c92p and c92n with the surfaces of the block 32. When the acceleration along the second axis, the proof mass 32 generates a displacement on the second axis, the capacitances of the second-axis sensing capacitors c92p and c92n change because of the change of the effective area. The changes of the two capacitances are in opposite so that the second axis acceleration can be detected by checking the difference of the capacitances of the two capacitors c92p and c92n. The detected signal can be fed back by a feedback circuit, which is not shown, to the second axis capacitor c92p and c92n, and the proof mass 32 remains still.

[0020] Two electrodes 93 are located on the surfaces of the boards 71, 72 corresponding to the proof mass 33. The electrodes 93 form two z-axis detection capacitors c93p and c93n with the surfaces of the proof mass 33. When the acceleration along the z-axis, the proof mass 33 generates a displacement on the z-axis, the distance change of the boards of the z-axis capacitors c93p and c93n

changes the capacitances of the capacitors. The changes of the two capacitances are in opposite so that the z-axis acceleration can be detected by checking the difference of the capacitances of the two capacitors c93p and c93n. The detected signal can be fed back by a feedback circuit, which is not shown, to the third axis capacitor c93p and c93n, and the proof mass 33 remains still.

[0021] The first embodiment includes three independent axes so that if only two axes are needed, the third axis is simply deleted.

[0022] Figure 3 shows a second embodiment of the three-axis accelerometer. Figure 3a shows a top view of the main structure made of electricity conductive material and includes three proof masses 31, 32, 33. The two proof masses 31, 32 are connected with each other and located around the proof mass 33 so as to form a proof mass 312. The proof mass 33 is connected to the proof mass 312 by flexible sensing beams 43, and the proof mass 312 is connected to the sensing beam 42 by sensing beams 41. Two ends of the sensing beam 42 are connected to a frame 2 or anchors 60. The frame 2 or the anchors 60 are fixed to boards 71 and 72. The sensing beam 43 makes the proof mass 33 movable only along the z-axis perpendicular to the surface of the boards. The sensing beams 41, 42 make the proof mass 312 movable along the first axis and the second axis parallel to the boards. The proof masses 31, 32 include elongate grooves 31t and 32t perpendicular to the first axis and the second axis.

[0023] As shown in Figure 3b, two sets of interposed stripe electrodes 91a and 91b parallel to the grooves 31t are located corresponding to the groove 31t on the board 71, 72 and electrically connected to the bond pads 91p and 91n respectively, so as to form a first axis detection capacitors c91p and c91n with the surface of the blocks 31. Figure 3c shows positional relationship between the electrodes 91a, 91b and the grooves 31t. When the acceleration along the first axis applies to the proof masses 31, 32, 33, generating a displacement along the first axis, the capacitances of the first-axis capacitors c91p and c91n change because of the change of the effective area. The changes of the two capacitances are opposite so that the first axis acceleration can be detected by checking the difference of the capacitances of the two capacitors c91p and c91n. The detected signal can be fed back by a feedback circuit,

which is not shown, to the first axis capacitor c91p and c91n, and the proof mass 31 remains still.

[0024] Two sets of interposed stripe electrodes 92a and 92b parallel to the grooves 32t are located corresponding to the grooves 32t in the boards 71, 72 and electrically connected to the bond pads 92p and 92n, respectively, so as to form a second axis detection capacitors c92p and c92n with the surface of the blocks 32. When the proof masses 31, 32, 33 are applied by the acceleration along the second axis, generating a displacement on the second axis, the capacitances of the second-axis capacitors c92p and c92n change because of the change of the effective area. The changes of the two capacitances are opposite so that the second axis acceleration can be detected by checking the difference of the capacitances of the two capacitors c92p and c92n. The detected signal can be fed back by a feedback circuit, which is not shown, to the second axis capacitor c92p and c92n, and the proof mass 32 remains still.

[0025] Two electrodes 93 are located on the surfaces of the boards 71, 72 and face the proof mass 33. The electrodes 93 form two z-axis detection capacitors c93p and c93n with the surfaces of the blocks 33. When the proof mass 33 is applied by the acceleration along the z-axis, the proof mass 33 generates a displacement along the z-axis and the distance change of the boards of the z-axis capacitors c93p and c93n changes the value of the capacitors. The changes of the two capacitances are opposite so that the z-axis acceleration can be detected by checking the difference of the capacitances of the two capacitors c93p and c93n. The detected signal can be fed back by a feedback circuit, which is not shown, to the third axis capacitor c93p and c93n, and the proof mass 33 remains still.

[0026] The acceleration along the first axis makes the proof masses 31, 32, 33 generate displacements along the first axis and the capacitances of the capacitors c92p and c92n on the second axis and the capacitors c93p and c93n on the z-axis is not affected if two ends of the electrodes 92a and 92b are not in flush with the two ends of the groove 32t, and the sides of the electrodes 93 are not in flush with the sides of the proof mass 33.

[0027]   Similarly, the acceleration along the second axis makes the proof masses 31, 32, 33 generate displacements along the second axis and the capacitances of the capacitors $c91p$ and $c91n$ on the first axis and the capacitors $c93p$ and $c93n$ on the z-axis are not affected if two ends of the electrodes 91a and 91b are not in flush with the two ends of the groove 31t, and the sides of the electrodes 93 are not in flush with the sides of the proof mass 33.

[0028]   The acceleration along the z-axis does not affect the proof masses 31, 32 so that the capacitances of the first axis capacitors $c91p$ and $c91n$ and the second axis capacitors $c92p$ and $c92n$ are not affected.

[0029]   If only the first axis acceleration and the z-axis acceleration are required to be detected, simply remove the sensing beam 42 and connect the sensing beam 41 to the frame or the anchor 2, and delete the groove 32t that is perpendicular to the second axis, the electrodes 92a, 92b on the boards 71, 72, and the bond pads $92p$ ad $92n$.

[0030]   The main structure of the third embodiment of the three-axis accelerometer is shown in Figure 4, and includes a proof mass 3 that is connected to the sensing beam 42 by flexible sensing beams 41.   The other end of the sensing beam 42 is connected to the frame 2 or the anchor 60.   The frame 2 or the anchors 60 are fixed to the boards 71, 72.   The sensing beams 41 and 42 form an L-shaped sensing beam so as to allow the proof mass 3 to be movable along the first axis, the second axis and movable along the z-axis.   The proof mass 3 includes a plurality of grooves 31t, 32t that are perpendicular to the first axis and the second axis, respectively, and an area that has no groove defined therein.

[0031]   The electrodes on the boards 71 and 72 are similar to those described in the second embodiment, as shown in Figure 3b.   The principle of acceleration detection on each axis is the same as described above.   The acceleration along the first axis does not affect the capacitors $c92p$, $c92n$ on the second axis and the capacitors $c93p$, $c93n$ on the z-axis, if the two ends of the electrodes 91a and 91b, 92a and 92 are not in flush with the two ends of the grooves 31t, 32t, and the electrode 93 is smaller than the area that has no groove of the proof mass 3.   The acceleration along the second axis does not affect the capacitors $c91p$, $c91n$ on the first axis and the capacitors $c93p$, $c93n$ on the z-axis.   The acceleration along the z-axis affects the

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capacitors c91p, c91n on the first axis, the change of the capacitances of the capacitors c91p and c91n that on the same side of the main structure is happened simultaneously. As aforementioned, the detection of the acceleration along the first axis is obtained by checking the difference of capacitances of the capacitors c91p, c91n, so that the differences can be canceled. If a feed back circuit is employed, the acceleration along z-axis does not affect the capacitors c91p, c91n on the first axis completely. Similarly, the acceleration along the z-axis also does not affect the capacitors c91p, c91n on the second axis completely.

[0032] If only the acceleration on the first axis and z-axis are required to be detected, simply deleting the sensing beam 42 and connecting the sensing beam 41 to the frame 2 or the anchor 60. Canceling the grooves 32t perpendicular to the second axis on the surfaces of the main structure, the electrodes 92a, 92b on the surface of the boards 71, 72, and the bond pads 92p, 92n.

[0033] Another type of the third embodiment of the accelerometer is disclosed in Figure 5, wherein the proof mass 3 has few grooves 31t, 32t perpendicular to the first axis and the second axis on the two surfaces. On the boards 71, 72, include the electrodes of the first axis capacitors c91p, c91n and the second axis capacitors c92p, c92n.

[0034] The detection of the accelerations of the x-axis and y-axis are the same as the preceding. The detection of the acceleration of the z-axis is dependent upon the output signals from the first axis capacitors c91p, c91n and the second axis capacitors c92p, c92n. The z-axis detection capacitor c93p is defined as the sum of c91p, c91n, c92p, and c92n on the front side of the main structure, the z-axis detection capacitor c93n is defined as the sum of c91p, c91n, c92p, and c92n on the back side of the main structure. When the acceleration along the z-axis applies to the proof mass 3, which generates a displacement along the z-axis, the capacitances of the z-axis capacitors c93p and c93n changes because of the change of the gaps of the capacitors. The z-axis acceleration can be detected by checking the difference of the capacitances of the two capacitors c93p and c93n. The detected signal can be fed back by a feedback circuit, which is not shown, to the z-axis capacitor c93p and c93n, and the proof mass 3 remains still.

[0035]   The acceleration along the first axis changes the capacitances of the first axis capacitors c91p, c91n with same value but in opposite direction, so that the sum is not changed.   Similarly, the acceleration along the second axis changes the capacitances of the second axis capacitors c92p, c92n with same value but in opposite direction, so that the sum is not changed.   Therefore, the acceleration on the first axis and the z-axis does not affect the z-axis capacitors c93p and c93n.

[0036]   The acceleration along the z-axis does not affect the detection on the first axis and the second axis, as aforementioned.

[0037]   If only the acceleration of the z-axis and the first axis is needed to be detected, the sensing beams 41, 42 are needed to be designed again to allow the proof mass 3 to move along the first axis which is parallel to the board and the z-axis which is perpendicular to the board, and canceling the groove 32t perpendicular to the second axis, the electrodes 91a, 92b on the boards 71, 72 and the bond pads 92p and 92n.

[0038]   If only the acceleration of the first axis and the second axis is needed, the sensing beams 41, 42 are needed to be designed again to allow the proof mass 3 to move along the first axis and the second axis both of which are parallel to the board.

[0039]   The grooves in the present invention may have different shapes such as a plurality of deeper recesses defined in the grooves, holes 31h, 32h defined through the grooves, or the elongate grooves are replaced with slots as shown in Figure 6.

[0040]   The L-shaped sensing beams in the second embodiment and the third embodiment may have different embodiments such as the L-shaped sensing beams shown in Figures 4-7, and are connected to the frame and the proof mass by different ways.

[0041]   The L-shaped sensing beam in the second embodiment can be exchanged with the other sensing beam, that is to say, the L-shaped sensing beam is located between two proof masses and the other sensing beam is connected to an outer proof mass and frame, or anchor such that the inner proof mass can only move in the first axis and the second axis parallel to the boards.   The outer proof mass can only be

movable along the z-axis, which is perpendicular to the board. The inner proof mass has a plurality of grooves 31t, 32t, which are perpendicular to the first axis and the second axis, and the two surfaces of the outer proof mass do not have grooves. The electrodes on the glass boards are changed accordingly.

[0042] The accelerometer can be made by surface micro-machining, dry etching, LIGA, bulk micro-machining. There is not necessary to make two deep and narrow spacing parallel surfaces and no high aspect ratio is required.

[0043] The embodiments mentioned above can be made on a (110) silicon chip by way of bulk micromachining, the device is in a parallelogram and the clamp angle between any two adjacent sides will be 109.48 or 70.52 degrees. For example, the second embodiment of the acceleration using (110) silicon chip by bulk micro-machining is shown in Figure 8, which is the same as the illustration in Figure 3 except the shape. The (110) silicon chip can be deeply vertical etched and automatically etching stop so that it is easily to manufacture the sensing beams and grooves, increasing the yield rate and the uniformity of the products. However, the sensing beams 41, 42 are non-orthogonal each other so that the first-axis and the second-axis output signals have to be transferred to an orthogonal coordinate system.

[0044] Defining a new coordinate system (x', y', z') formed by rotating an angle (19.48 degrees) from an original coordinate system (x, y, z). If the sensing beams 41, 42 are parallel to the y' axis and the x axis as shown in Figure 8, then the first detection axis is parallel to the x' axis and the second detection axis is parallel to the y axis, so that the component of the detected accelerations are Ax' and Ay respectively. The (Ax', Ay) components has to be transferred to an orthogonal coordinate (x, y, z) or (x', y', z'). Assuming the coordinate of the system is (x, y, z), the two coordinates in Figures 8 can be transferred from (Ax', Ay) to (Ax, Ay).